The Sao Paulo/Berkeley Connection

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Abstract

Over the past 15 years, a very fruitful collaboration has been established between Iuda Goldman, his colleagues and students at the USP, and my group at Lawrence Berkeley National Laboratory (LBNL). In this brief report, I describe several of the projects that we have undertaken together.

Introduction

Sometime in 1987, I received a telephone call from a physics professor at the University of Sao Paulo named Iuda Goldman. He told me that he had read some of my papers and that he would like to meet me and discuss the possibility of starting a collaboration. I was, of course, flattered to learn that someone had actually read my papers and found them interesting. I invited Iuda to visit me at LBNL. Not long after this call, Iuda came for what would be the first of many visits to Berkeley. In 1989, I visited Iuda and his colleagues at the USP and was introduced to a graduate student named Tiago da Cruz. Iuda thought it would be a good idea for Tiago to come to LBNL as a post doc and to work in my group. Once Tiago finished his thesis, he came to Berkeley for two years during which he worked with us on a large number of experiments, mostly related to problems in cosmic ray chronometry. Since then, I have visited Iuda at the USP twice more, and Iuda has come to LBNL on average about once a year. During these visits, we have collaborated on a number of different experiments that I describe briefly below.

Weak γ rays from the electron-capture decay of ^{194}Au

The electron-capture decay of ^{194}Au produces more than 160 gamma rays ranging in energy from 59 to 1812 keV. Although this decay had been extensively studied in the past, Iuda and his colleagues from the USP felt it would be useful to perform a modern study of this decay. As a result, two sets of measurements were performed: one in Sao Paulo and one in Berkeley. At the USP, a source of ^{194}Au was produced by bombarding a ^{194}Pt target with 10 MeV protons from the IPEN cyclotron. The resulting ^{194}Au activity was counted in singles using a Compton-suppressed germanium detector. In Berkeley, a source of ^{194}Hg was produced via the ^{197}Au (p,4n) reaction using 40-MeV protons from the 88-Inch Cyclotron. γ-γ coincidence data from the ^{194}Hg source (with ^{194}Au in equilibrium) was obtained by using the HERA array of 20 Compton-suppressed germanium detectors. Analysis of these two sets of data was performed in Sao Paulo and resulted in the placement of 34 new weak transitions in the decay scheme of ^{194}Au. A short paper describing these results was published in Physical Review C [1], and these experiments formed the basis of the Ph. D. thesis of Ricardo R. P. Teixeira.

^{44}Ti: half-life, production and destruction cross sections

The long-lived radioisotope ^{44}Ti is of considerable astrophysical interest. ^{44}Ti is one of the few long-lived γ-ray emitting nuclides expected to be produced in substantial amounts during a supernova explosion. Its characteristic 1157-kev γ ray was observed from the young supernova remnant Cassiopeia A. In order to compare these γ-ray results to supernova models, one needs to know a number of properties of ^{44}Ti. For example: what is the half-life of ^{44}Ti? As of 1996, published values of this half-life ranged from 39.0 to 66.6 years. Another important issue is what is the rate of destruction of ^{44}Ti in a supernova explosion? One of the possible destruction mechanisms is the ^{44}Ti (n,γ) ^{45}Ti reaction. Thus Iuda, his colleagues and students at the USP, together with members of my group at LBNL set out to study ^{44}Ti.

We began trying to produce enough ^{44}Ti to make sources and targets suitable for half-life and neutron cross section measurements. Bombardments were carried out at the IPEN cyclotron in Sao Paulo and at the 88-Inch Cyclotron in Berkeley. We made ^{44}Ti via the ^{45}Sc(p,2n) ^{44}Ti reaction and based our production estimates on previously published cross sections. The amount of ^{44}Ti that we actually produced was always substantially less than what we had expected. Thus we decided to remeasure the excitation function for the ^{45}Sc(p,2n) reaction. We found that the previously published data greatly overestimated the cross sections for the production of ^{44}Ti most likely because of the presence of an unknown long-lived positron emitter in the samples counted by the earlier investigators. A paper describing our measurements of the excitation function for this reaction and other reactions on ^{45}Sc was published in Physical Review C [2].

We then began a set of experiments to determine the half-life of ^{44}Ti. We used a direct γ-ray counting technique to observe the small decrease in the counting rate of the 1157-keV ^{44}Ti γ ray over a period of 1 to 2 years. In order to ensure that our results were not affected by changes in detector or electronics performance, both of our measurements were made using a standard that was mixed into the source of ^{44}Ti. In the first measurement that lasted 2 years, we compared the number of 1157-kev ^{44}Ti γ rays to those of 1274-keV γ rays from ^{22}Na. In the second experiment that lasted 1 year, we compared the numbers of 1157-keV ^{44}Ti γ rays to those of 1064-keV γ rays from ^{207}Bi. The results of these two experiments agreed with very well with each other and led us to report a best value of 62 $\pm$ 2 years for the half-life of ^{44}Ti. A paper describing these results was published in Physical Review C [3]. After our paper was submitted for publication, four other groups reported results for the half-life of ^{44}Ti that all agreed with our result. Thus the issue of the half-life of this important isotope has been resolved.

Our final experiment on ^{44}Ti was a measurement of its thermal neutron capture cross section. This experiment was performed in collaboration with Professor Kenneth Krane at the Oregon State University (OSU) TRIGA reactor facility. We irradiated a sample of ^{44}Ti with thermal neutrons and the counted the resulting ^{45}Ti activity using a germanium detector. The result we obtained of 1.1 $\pm$ 0.2 barns was found to be in reasonable agreement with the results of a theoretical direct capture calculation. A report on this experiment was published in Physical Review C [4]. I should point out that Renato Ejnisman played a major role in this experiment and in the measurement of the ^{45}Sc(p,2n) excitation function even though at the time he was busy completing his Ph. D. on a totally different topic at the University of Rochester.

Half-life of the 6.3-keV isomer in ^{121}Sn

The ground and first two excited states in ^{117}Sn, ^{119}Sn, and ^{121}Sn originate from the $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ shell-model configurations. Consequently, these nuclides each have a long-lived isomer that predominately decays by an M4 isomeric γ-ray transition. The $h_{11/2}$ configuration assignment may be tested with this transition provided that reliable values of the isomer half-life were available for all three isotopes of tin. However, this is not the case for ^{121m}Sn, where the following discrepant values were reported in the literature: 76.3 $\pm$ 6.6 yr , 55$\pm$5 yr, 40$\pm$10 yr, and 25 yr. Iuda, Eddie Browne, Greg Rech, and I therefore decided to measure the half-life of ^{121m}Sn. In the same experiment we measured a half-life of 21.8$\pm$0.3 yr for ^{210}Pb. This latter result agrees well with the recommended value of 22.3$\pm$0.2 yr and thus confirms the good performance of our equipment and adequate analysis of our data. We deduced the half-life of ^{121m}Sn by measuring the decrease in the 37.1-keV γ-ray count rate over a period of 1.2 years. Since such a change is expected to be about 1.5%, good statistics (more than $\approx 1 \times 10^6$ events in the peak) and a precise reckoning of the spectral areas are required as well as a stable response of the data acquisition system. Because of its long and well known half-life of 432.2 $\pm$ 0.7 yr we used the 59.5-keV peak from ^{241}Am α decay to test the stability of the electronics and to correct the data for systematic errors that could have originated from changes in the Ge detector response. Our result of 43.9$\pm$0.5 yr for the half-life of ^{121m}Sn may be compared with 49 yr, an estimate that we have deduced from the reduced transition probabilities of the M4 isomeric transition in ^{117m}Sn and ^{119m}Sn. This agreement supports the $11/2^-$ spin and parity assignments to ^{121m}Sn. A paper describing these results has been submitted for publication [5].

Neutron-capture cross sections of radioactive nuclei

For several years, Iuda has been interested in the thermal neutron capture cross sections of radioactive isotopes. In collaboration with Ken Krane from OSU, Iuda and I have performed experiments to measure these cross sections for ^{44}Ti, ^{148}Gd, ^{32}Si, ^{37}S, and ^{90}Y. These experiments are all done using an activation technique suggested by Iuda. In the cases of ^{44}Ti, ^{148}Gd, and ^{32}Si, we purchased these long-lived isotopes from Los Alamos National Laboratory, irradiated them at the OSU TRIGA reactor and then counted each sample to look for the decay of the (n,γ) product. As described above, we measured a cross section of 1.1 $\pm$ 0.2 barns for ^{44}Ti. We have a preliminary result for ^{148}Gd, but further measurements are needed. For ^{32}Si we performed a test run, but discovered that the presence of an ^{28}Al contaminant limited our sensitivity. Improvements are now underway at the OSU reactor's rabbit facility that should allow us to complete this measurement soon. The experiments on ^{37}S and ^{90}Y make use of a clever idea suggested by Iuda. Consider the irradiation of stable ^{36}S by neutrons. Neutron capture on ^{36}S produces the short-lived isotope ^{37}S ($t_{1/2}$ = 5 minutes). After about 20 minutes, the ^{37}S abundance reaches its saturation value and then remains constant. Thus one has a constant and measurable number of ^{37}S nuclei that serve as targets for neutron capture to produce the longer lived isotope ^{38}S ($t_{1/2}$ = 2.8 hours). Thus by irradiating a target of ^{36}S for something like two hours and then counting the target to measure the yield of ^{38}S, one can determine the neutron capture cross section of ^{36}S. A test run on this system was performed a few weeks ago during Iuda's most recent visit to the U.S. Data from this experiment are now being analyzed. An experiment to measure the cross section for ^{90}Y using a similar technique is scheduled for later this month.

Conclusions

From the projects described above, I think it is clear that the collaboration between Iuda, his colleagues and students from the USP, and my group at Lawrence Berkeley National Laboratory has been both very productive and mutually beneficial. All of us at LBNL wish Iuda a very happy 70th birthday, and we hope that Iuda (and Clea) will continue to visit us and that we will perform interesting new experiments together for many years to come.

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